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MINISTRY OF TECHNOLOGY

# EXPLOSIVES RESEARCH AND DEVELOPMENT ESTABLISHMENT

TECHNICAL MEMORANDUM No. 21/M/66

## The Accelerated Ageing of some Commercial Polyurethane Rubbers

B.L. Hollingsworth
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WALTHAM ABBEY
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# The Accelerated Ageing of some Commercial Polyurethane Rubbers

by

B.L. Hollingsworth, K.J. Ledbury and A.L. Stokoe

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Reference: WAC/174/020

## 1. SUMMARY

Nineteen commercial polyester urethane rubbers, and one commercial polyether urethane rubber ~~have been~~ subjected to accelerated laboratory ageing for periods of up to two years under hot/dry, hot/wet, and hot/humid conditions, and for up to two years immersed in Standard Test Fluid.

The results obtained on the polyether urethane were similar to those obtained in previous trials. The best polyester urethane (a development material) had a life under hydrolytic conditions of five to eight times that normally expected from commercially available polyester urethanes. ( )

## 2. INTRODUCTION

During the past five years, polyurethane rubbers have been increasingly proposed for use in Service equipment, such as solid tyres, tank track pads, seals, bellows and flexible fuel tanks. These rubbers are attractive because of their relative ease of fabrication, high strength and elongation, excellent fuel and oxidation resistance, and good abrasion properties. To date, there has been little Service use due to the poor hydrolytic stability of the polyester urethanes. While the polyether urethanes have superior hydrolytic stability, their mechanical properties and resistance to petrol are normally inferior to those of the polyester urethanes.

The commercial manufacturers recognise this limitation on the wider application of polyester/polyurethane rubbers, and in the past two to three years have devoted considerable efforts to the production of materials of increased hydrolytic stability. It was, therefore, decided to examine the ageing behaviour of a range of commercially-produced polyurethane rubbers under hot/dry and hot/wet conditions, and the effect of immersion in petrol for protracted periods. One polyether urethane and nineteen polyester urethanes were included in the trial. Most of the polyester urethanes contained an anti-hydrolysis agent to increase their hydrolytic stability. In a similar trial, both polyester and polyether urethanes were examined some years ago at E.R.D.E. (1), but the present trial was mounted due to the claim that significant improvements in the hydrolytic stability of the polyester urethane rubbers have been made.

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3. MATERIALS

The polyurethane rubbers are referred to throughout the Memo by code numbers. All were supplied by the manufacturers as sheets of cured rubber. The rubbers P.U.17 to P.U.20 are later modifications of P.U.7.

4. EXPERIMENTAL

British Standard type C-dumb-bell test pieces (2) were cut from the sheets supplied, and the width and thickness measured before exposure to the test conditions. Dumb-bells, in sets of four, were suspended in loosely stoppered glass tubes and exposed to some or all of the following environments:

| | |
|---|---|
| Hot/dry | Suspended in air at 40°, 70° or 100°C. |
| Hot/wet | Immersed in boiled out distilled water at 40°, 70° or 90°C. |
| Hot/humid | Suspended above boiled out distilled water at 40°, 60°, 70° or 90°C. |
| Standard Test Fluid | Immersed in Standard Test Fluid at 40° or 65°C. |

Standard Test Fluid (S.T.F.) consists of a 70/30 v/v mixture of iso-octane and toluene, and is intended to represent a standard "medium to high aromatics content" petrol (3).

The charged tubes were placed in circulating air ovens, in which the temperatures did not vary by more than ± 0.5°C from the test temperature. At the end of each exposure period, the required number of tubes were removed from the ovens, and the tubes and contents conditioned at room temperature (approximately 15°C) for 24 hours before testing. After the conditioning period, the groups of four specimens were removed from the tubes, dried from superficial liquid, and tested for hardness, elongation at break, and tensile strength as quickly as possible. Hardness was measured using a micro-indentometer, and the tensile properties were measured by British Standards methods (2,4) on a Hounsfield Tensometer. Specimens cut from the materials as received were tested by the same methods, and the results used as "unaged" reference points.

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## 5. RESULTS AND DISCUSSION

The results are given in Tables 1 to 5 (pp 7 - 11), and are discussed below.

### 5.1 Ageing Under Hot/Dry Conditions

Samples P.U.3 to P.U.10 and P.U.12 to P.U.20 were not aged under hot/dry conditions, due to the limited amount of each available. The polyester urethane P.U.1 had high initial strength of 6190 p.s.i., but in 24 weeks at 70°C, its strength fell to 30 p.s.i. At 40°C, the deterioration was much less rapid, and after 2 years its strength was still 1360 p.s.i. The elongation at break and the hardness showed only insignificant changes until the tensile strength reached a very low value. This feature is common to all the polyurethanes examined. After ageing for 52 weeks at 70°C and 40°C, P.U.2 had lost 62 and 40 per cent respectively of its initial tensile strength of 2930 p.s.i. Again, only small changes in elongation at break and hardness occurred during 52 weeks ageing.

The polyether urethane P.U.11 deteriorated more slowly than the polyester urethanes, retaining approximately one-third of its initial tensile strength after 52 weeks at 100°C. After 52 weeks at 70° and 40°C, the tensile strength was reduced by 52 and 46 per cent respectively. The elongation at break and hardness were, again, practically unchanged.

### 5.2 Ageing Under Hot/Wet Conditions

After immersion in water at 70°C, sample P.U.1 became too weak to test after 2 weeks, and sample P.U.6 became too weak to test after 3 weeks. These results are typical of the results normally obtained with polyester urethanes. Sample P.U.2 was completely degraded after 4 weeks immersion, while samples P.U.8 and P.U.9 only became too weak to test after 8 weeks. P.U.7, of which only a small sample was received, had only lost twenty per cent of its initial tensile strength after immersion for 4 weeks. The polyether polyurethane P.U.11 dropped from an initial tensile strength of 4090 p.s.i. to a strength of 480 p.s.i. after 52 weeks immersion, a result typical of the polyether urethanes. Sample P.U.10 dropped in tensile strength from 2530 p.s.i. to 840 p.s.i. after 12 weeks immersion. This result is unusual for a polyester urethane, and other evidence indicates that this sample may be a mixed polyester polyether urethane.

In general, the samples showed increased elongation at break in the period before very drastic reductions in tensile strength had taken place. This is attributed to absorption of water, which then acts as a plasticiser.

/5.3 .....

5.3 Ageing Under Hot/Humid Conditions

Most tests have been carried out at 70°C, in air saturated with water vapour above boiled out distilled water. For convenience, this has been considered to be 100 per cent relative humidity. The results are generally similar to those obtained on immersion in water at 70°C. P.U.1 and P.U.6 were too weak to test after 2 weeks exposure, and P.U.2, 3, 4, 5 and 8 after 4 weeks. P.U.9 and P.U.16 were too weak after 8 weeks, and P.U.12, 13 and 15 after 12 weeks. The samples P.U.17 to 19, which are similar to P.U.7, only failed after 20 weeks, while the best of the variants on P.U.7, sample P.U.20, still retained some strength after 24 weeks exposure. The polyether urethane P.U.11 showed a similar reduction in tensile strength after 52 weeks exposure, to that obtained by immersion in water for the same period.

The samples again showed increases in elongation at break in the early stages of exposure, but the increases were not so great as those obtained by immersion in water. The loss in tensile strength with time is comparable, whether the sample is immersed in water or held in an atmosphere of 100 per cent relative humidity, with the latter condition causing slightly more severe degradation. Sample P.U.7 was reduced from a tensile strength of 4450 p.s.i. to 3850 p.s.i. by immersion in water at 70°C for 4 weeks while at 100 per cent relative humidity at 70°C; in four weeks the strength dropped to 3660 p.s.i. Similarly, P.U.10 dropped from 2530 to 840 p.s.i. after immersion for 12 weeks at 70°C, and dropped from 2530 to 780 p.s.i. after 12 weeks at 70°C and 100 per cent relative humidity. The slightly greater rate of degradation under humid conditions is thought to be due to the presence of a higher concentration of oxygen in the humid atmosphere than in the boiled out distilled water used for the hot/wet conditions. Whilst the polyurethanes are generally fairly resistant to oxidation, a small amount of oxidation may occur in the rubber in the water-swollen state, leading to the difference in severity between hot/wet and hot/humid ageing.

The results on P.U.11 show that deterioration, as measured by tensile strength, is very temperature dependent. Approximately the same degree of degradation is reached after exposure for 2 weeks at 90°C, for 12 weeks at 70°C or more than one year at 40°C.

5.4 Immersion in Standard Test Fluid

In S.T.F. at 40° and 65°C, the tensile strength of P.U.1 showed a sharp fall during the first week's immersion, and then a slow steady drop. After 2 years' immersion, the sample still retained some useful strength. The elongation at break and the hardness both showed marked changes after one week's immersion, and then little change until the tensile strength had fallen to a low value. The volume swelling did not change significantly

/during .....

during the test period, indicating that equilibrium swelling has been obtained during the first week of immersion. The initial change in physical properties is similar to that expected for swelling and plasticisation of a rubber by a fluid. When approximately 5 per cent by volume of water was added to the S.T.F. and the tube shaken occasionally during the test period, the deterioration of P.U.1 was more rapid than in S.T.F. alone. This pattern of change in physical properties is common to all the polyester urethanes examined, indicating that during the first 12 weeks of immersion in S.T.F., swelling and plasticisation are the predominating causes of change, and not degradation. After longer periods, traces of moisture in the S.T.F. appear to have caused some hydrolytic degradation.

No tests were carried out on P.U.11 due to its limited availability. It is known that the polyether urethanes swell considerably in S.T.F., and suffer a greater loss in physical properties than do the polyester urethanes in the same time under the same conditions. This is shown by P.U.10 which is thought to be a mixed polyester polyether urethane.

## 6. CONCLUSIONS

The commercial polyester and polyether urethanes examined slowly deteriorate when subjected to hot/dry conditions for long periods. When immersed in water or in contact with moisture at elevated temperatures, the deterioration of the polyester urethanes is rapid, and the rate is markedly temperature dependent. Under similar conditions, the polyether urethanes deteriorate more slowly. Immersion of the polyester urethanes in S.T.F. at elevated temperatures leads first to swelling and plasticisation, and then to slow deterioration, unless water is present, when rapid degradation takes place.

Elongation at break and hardness do not appear to be satisfactory physical properties from which to measure the degradation taking place in the polyurethanes.

While the rate of degradation of the polyester urethanes examined in this trial is still greater than could be accepted in a rubber for Service use, the best samples submitted (P.U.17 to 20) have shown a life of 5 to 8 times that which has hitherto been anticipated from polyester urethanes. Continuing developments with the P.U.17 to 20 series hold out the hope that a polyester urethane rubber which will meet Service requirements with respect to hydrolytic stability will be produced in the fairly near future.

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7. REFERENCES

1. Harding, G.W., E.R.D.E. Technical Memorandum No. 10/M/60.

2. B.S. 903: Part A 2: 1955.

3. B.S. 2751: 1956.

4. B.S. 903: Part A 7: 1957.

/TABLE 1 .....

TABLE 1

Effect of Hot/Dry Conditions on Polyester Urethanes P.U.1 and P.U.2

| Rubber | | P.U.1 | | | P.U.2 | | |
|---|---|---|---|---|---|---|---|
| Conditions of Test | Period of Exposure, weeks | T.S. | $E_b$ | H | T.S. | $E_b$ | H |
| Material as received | 0 | 6190 | 675 | 87 | 2930 | 540 | 92 |
| Dry $40^\circ \pm 0.5^\circ C$ | 1 | 6020 | 670 | 76 | 2820 | 520 | 92 |
| | 2 | 5620 | 740 | 73 | | | |
| | 4 | 6340 | 685 | 74 | | | |
| | 12 | 5840 | 700 | 73 | 2960 | 520 | 92 |
| | 24 | 4930 | 590 | 73 | | | |
| | 52 | 3870 | 630 | 69 | 1750 | 510 | 92 |
| | 104 | 1360 | 720 | 71 | | | |
| Dry $70^\circ \pm 0.5^\circ C$ | 1 | 6200 | 675 | 75 | | | |
| | 2 | 5820 | 715 | 77 | 2780 | 440 | 90 |
| | 4 | 4550 | 635 | 75 | 2840 | 540 | 90 |
| | 12 | 2700 | 750 | 65 | 2540 | 550 | 91 |
| | 24 | 30 | 340 | <30 | | | |
| | 52 | Too weak to test | | | 1100 | 330 | 86 |

The following abbreviations are used throughout Tables 1 to 5

T.S. = Tensile Strength, pounds/inch$^2$

$E_b$ = Elongation at break, per cent.

H = Hardness, British Standard degrees.

/TABLE 2 .....

TABLE 2

Effect of Hot/Wet and Hot/Humid Conditions on Polyest

| Rubber | | P.U.1 | | | P.U.2 | | | P.U.3 | | | P.U.4 | | | P.U.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conditions of Test | Period of Exposure, weeks | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ |
| Material as received | | 6190 | 675 | 87 | 2930 | 540 | 92 | 3130 | 560 | 94 | 3120 | 550 | 93 | 3990 | 510 |
| 60°C, 100% r.h. | 0.5 | | | | | | | 2000 | 550 | 90 | 2040 | 600 | 89 | 3260 | 51( |
| | 1.0 | | | | | | | 1660 | 490 | 91 | 1750 | 510 | 90 | 2590 | 510 |
| | 2 | | | | | | | 1200 | 480 | 91 | 1230 | 530 | 90 | 2710 | 510 |
| | 4 | | | | | | | 600 | 480 | 88 | 490 | 150 | 88 | 620 | 150 |
| 70°C, 100% r.h. | 1 | 500 | 790 | 42 | | | | 960 | 530 | 89 | 1030 | 530 | 89 | 860 | 370 |
| | 2 | Too weak to test | | | 680 | 330 | 83 | 660 | 150 | 89 | 680 | 110 | 92 | 500 | 85 |
| | 4 | | | | Too weak to test | | | Too weak to test | | | Too weak to test | | | Too weak t | |
| | 8 | | | | | | | | | | | | | | |
| | 12 | | | | | | | | | | | | | | |
| 70°C, immersed in water. | 1 | 1200 | 790 | 42 | 660 | 350 | 81 | | | | | | | | |
| | 2 | Too weak to test | | | Too weak to test | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | |
| | 8 | | | | | | | | | | | | | | |
| | 12 | | | | | | | | | | | | | | |

TABLE 2

umid Conditions on Polyester Urethanes P.U.1 to P.U.10

| P.U.4 | | | P.U.5 | | | P.U.6 | | | P.U.7 | | | P.U.8 | | | P.U.9 | | | P.U.10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H |
| 20 | 550 | 93 | 3990 | 510 | 95 | 5570 | 722 | 86 | 4450 | 380 | 98 | 3540 | 530 | 67 | 2440 | 615 | 66 | 2530 | 425 | 69 |
| 40 | 600 | 89 | 3260 | 510 | 95 | | | | | | | | | | | | | | | |
| 50 | 510 | 90 | 2590 | 510 | 96 | | | | | | | | | | | | | | | |
| 30 | 530 | 90 | 2710 | 510 | 95 | | | | | | | | | | | | | | | |
| 90 | 150 | 88 | 620 | 150 | 93 | | | | | | | | | | | | | | | |
| 30 | 530 | 89 | 860 | 370 | 93 | Too weak to test | | | 3910 | 370 | 98 | 2340 | 645 | 63 | 1690 | 580 | 64 | 1200 | 490 | 76 |
| 80 | 110 | 92 | 500 | 85 | 94 | | | | 3650 | 385 | 97 | 1460 | 655 | 68 | 1430 | 640 | 69 | 1600 | 510 | 69 |
| o weak to test | | | Too weak to test | | | | | | 3660 | 365 | 97 | 100 | 560 | 67 | 710 | 670 | 71 | 1120 | | 76 |
| | | | | | | | | | | | | Too weak to test | | | Too weak to test | | | 830 | 530 | 76 |
| | | | | | | | | | | | | | | | | | | 780 | 660 | 76 |
| | | | | | | 1020 | 795 | 30 | | | | 2130 | 680 | 65 | 2000 | 690 | 63 | 1300 | 530 | 76 |
| | | | | | | Too weak to test | | | 3850 | 370 | 97 | 450 | 680 | 69 | 1140 | | 68 | 1000 | | 80 |
| | | | | | | | | | | | | Too weak to test | | | Too weak to test | | | 1010 | 690 | 75 |
| | | | | | | | | | | | | | | | | | | 840 | 760 | |

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/TABLE 3 .....

TABLE 3

Effect of Wet and Dry Standard Test Fluid on Polyest r U

| Rubber | | P.U.1 | | | | P.U.2 | | | | P.U.3 | | | P.U.4 | | | P.U | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conditions of Test | Period of Exposure, weeks | T.S. | $E_b$ | H | S* | T.S. | $E_b$ | H | S | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | E |
| Material as received | | 6190 | 675 | 87 | - | 2930 | 540 | 92 | - | 3130 | 560 | 94 | 3120 | 550 | 93 | 3990 | 5 |
| Immersion in S.T.F. at 65° ± 0.5°C | 1 | 4490 | 740 | 67 | 13.8 | | | | | | | | | | | | |
| | 2 | 3710 | 710 | 64 | 13.5 | 2290 | 720 | 82 | 17.3 | | | | | | | | |
| | 4 | 3700 | 690 | 66 | 13.9 | 2190 | 730 | 82 | 17.4 | | | | | | | | |
| | 12 | 3050 | 690 | 63 | 13.4 | 2030 | 700 | 82 | 19.4 | | | | | | | | |
| | 24 | 2130 | 675 | 64 | 14.0 | | | | | | | | | | | | |
| | 52 | 530 | 610 | 43 | | 1480 | | 82 | | | | | | | | | |
| | 104 | 230 | 10 | <30 | 15.6 | | | | | | | | | | | | |
| Immersion in S.T.F. at 40° ± 0.5°C | 1 | 4820 | 740 | 67 | 13.3 | | | | | 2210 | 650 | 90 | 2340 | 680 | 91 | 2520 | 6 |
| | 2 | 4340 | 725 | 68 | 13.5 | 2190 | 680 | 86 | 15.1 | | | | | | | | |
| | 4 | 4380 | 715 | 68 | 13.4 | 2250 | 690 | 86 | 15.5 | 1980 | 680 | 90 | 2040 | 700 | 90 | 2810 | 6 |
| | 12 | 4290 | 710 | 67 | 13.3 | 2260 | 670 | 86 | 15.4 | | | | | | | | |
| | 24 | 3340 | 740 | 66 | 13.9 | | | | | | | | | | | | |
| | 52 | 1690 | 655 | 54 | | 1900 | | 88 | 15.8 | | | | | | | | |
| | 104 | 570 | 680 | <30 | 13.1 | | | | | | | | | | | | |
| Immersion in S.T.F. and 5% v/v water at 40°C | 3 | 3270 | 745 | 69 | | | | | | | | | | | | | |
| | 5 | 2590 | 630 | | | | | | | | | | | | | | |
| | 12 | 990 | 740 | | | | | | | | | | | | | | |

*S = Volume Swell, per cent

A

TABLE 3

nd Dry Standard Test Fluid on Polyester Urethanes P.U.1 to P.U.10

| | P.U.3 | | | P.U.4 | | | P.U.5 | | | P.U.6 | | | P.U.7 | | | P.U.8 | | | P.U.9 | | | P.U.10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H |
| | 3130 | 560 | 94 | 3120 | 550 | 93 | 3990 | 510 | 95 | 5570 | 722 | 86 | 4450 | 380 | 98 | 3540 | 530 | 67 | 2440 | 615 | 66 | 2530 | 425 | 69 |
| | | | | | | | | | | 4700 | 900 | <30 | | | | 1830 | 610 | 66 | 1900 | 630 | 68 | 1090 | 370 | 79 |
| 5 | | | | | | | | | | 3620 | 740 | <30 | | | | 2450 | 560 | 67 | 1830 | 630 | 67 | 1170 | 380 | 79 |
| 4 | | | | | | | | | | 4320 | 860 | <30 | 3590 | 340 | 92 | 2620 | 615 | 68 | 1890 | 670 | 68 | 1790 | 480 | 83 |
| 4 | | | | | | | | | | | | | | | | 2250 | 670 | | 2065 | 600 | | 1360 | 450 | |
| | 2210 | 650 | 90 | 2340 | 680 | 91 | 2520 | 620 | 93 | | | | | | | | | | | | | | | |
| 5 | 1980 | 680 | 90 | 2040 | 700 | 90 | 2810 | 600 | 92 | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | | | | | | |

*S = Volume Swell, per cent

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/TABLE 4 .....

TABLE 4

The Effect of Hot/Humid Conditions and Immersion in Standard Test Fluid on Pol

| | | P.U.12 | | | P.U.13 | | | P.U.14 | | | P.U.15 | | | P.U.16 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conditions of Test | Period of Exposure, weeks | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ |
| Material as received | | 2370 | 675 | 80 | 3370 | 460 | 76 | 5460 | 670 | 95 | 3430 | 780 | 79 | 3750 | 480 |
| 60° ± 0.5°C, 100% r.h. | 1 | 1730 | 810 | 64 | | | | 4090 | 680 | 92 | 2100 | 800 | 73 | 3280 | 475 |
| | 2 | 1660 | 715 | 67 | | | | 4650 | 625 | 92 | 2460 | 810 | 77 | 2870 | 430 |
| | 3 | 1520 | 770 | 64 | | | | 4860 | 640 | 91 | 1880 | 840 | 78 | 2560 | 450 |
| | 4 | 1790 | 700 | 63 | 3420 | 480 | 73 | 4410 | 680 | 89 | 2080 | 840 | 79 | 2320 | 435 |
| | 8 | 1190 | 790 | 61 | 3450 | 480 | 70 | | | | 1210 | 770 | 74 | 640 | 10 |
| | 12 | | | | 2760 | 475 | 68 | | | | | | | Too weak to | |
| | 16 | 540 | 545 | | 2546 | 475 | 58 | 3010 | 740 | 98 | 1190 | 800 | 87 | | |
| | 24 | Too weak to test | | | 1640 | 545 | 41 | | | | | | | | |
| | 40 | | | | | | | 2530 | 690 | 93 | | | | | |
| | 52 | | | | | | | 2180 | 805 | 88 | | | | | |
| 70° ± 0.5°C 100% r.h. | 1 | 1470 | 690 | 57 | 2970 | 440 | 72 | 4210 | 700 | 90 | 1940 | 900 | 66 | 3410 | 560 |
| | 2 | 1400 | 680 | 61 | | | | 4010 | 670 | 90 | 1628 | 870 | 86 | 2380 | 500 |
| | 3 | 1220 | 660 | 57 | | | | 4170 | 685 | 90 | 1120 | 830 | 71 | 1190 | 335 |
| | 4 | 1290 | 700 | 59 | 2960 | 485 | 68 | 4150 | 690 | 85 | 1150 | 800 | 69 | 1300 | 350 |
| | 8 | 510 | 470 | 55 | 1610 | 556 | 38 | | | | 780 | 660 | 70 | Too weak to | |
| | 12 | Too weak to test | | | Too weak to test | | | Insufficient sample for further tests | | | Too weak to test | | | | |
| | 16 | | | | | | | | | | | | | | |
| | 20 | | | | | | | | | | | | | | |
| | 24 | | | | | | | | | | | | | | |
| Immersion in S.T.F. at 40°C | 2 | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | |
| | 8 | | | | | | | | | | | | | | |
| | 12 | | | | | | | | | | | | | | |
| Swelling in S.T.F. at 40°C | 6 days | | | | | | | | | | | | | | |

Two samples of P.U.20 were received. The test data on the second sample ar

TABLE 4

ns . nd Immersion in Standard Test Fluid on Polyester Urethanes P.U.12 to P.U.20

| P.U.14 | | | P.U.15 | | | P.U.16 | | | P.U.17 | | | P.U.18 | | | P.U.19 | | | P.U.20 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H | T.S. | $E_b$ | H |
| 60 | 670 | 95 | 3430 | 780 | 79 | 3750 | 480 | 92 | 3490 | 370 | 93 | 4960 | 500 | 84 | 5600 | 550 | 84 | *3510<br>4540 | 300<br>435 | 96<br>90 |
| 90 | 680 | 92 | 2100 | 800 | 73 | 3280 | 475 | 97 | | | | | | | | | | | | |
| 50 | 625 | 92 | 2460 | 810 | 77 | 2870 | 430 | 89 | | | | | | | | | | | | |
| 60 | 640 | 91 | 1880 | 840 | 78 | 2560 | 450 | 87 | | | | | | | | | | | | |
| 10 | 680 | 89 | 2080 | 840 | 79 | 2320 | 435 | 88 | | | | | | | | | | | | |
| | | | 1210 | 770 | 74 | 640 | 10 | 95 | | | | | | | | | | | | |
| | | | | | | Too weak to test | | | | | | | | | | | | | | |
| 010 | 740 | 9[illegible] | 1190 | 800 | 87 | | | | | | | | | | | | | | | |
| 30 | 690 | 93 | | | | | | | | | | | | | | | | | | |
| 80 | 805 | 88 | | | | | | | | | | | | | | | | | | |
| 210 | 700 | 90 | 1940 | 900 | 66 | 3410 | 580 | 86 | 3270 | 435 | 95 | 3920 | 570 | 87 | 4340 | 660 | 79 | 4290 | 485 | 94 |
| 010 | 670 | 90 | 1628 | 870 | 86 | 2380 | 500 | 86 | 3070 | 410 | 76 | 3270 | 595 | 76 | 3700 | 730 | 76 | 4310 | 510 | 79 |
| 170 | 685 | 90 | 1120 | 830 | 71 | 1190 | 335 | 90 | | | | | | | | | | | | |
| 150 | 690 | 85 | 1150 | 800 | 69 | 1300 | 350 | 97 | 2740 | 430 | 94 | 3000 | 595 | 87 | 2680 | 730 | 87 | 3830<br>4030 | 470<br>505 | 92<br>92 |
| | | | 780 | 660 | 70 | Too weak to test | | | 1560 | 410 | 92 | 1370 | 600 | 90 | 1510 | 860 | 94 | *2640<br>2040 | 550<br>530 | 93<br>90 |
| nsufficient ample for urther tests | | | Too weak to test | | | | | | 810 | 370 | 99 | 820 | 500 | 99 | 740 | 670 | 97 | 1990<br>1320 | 545<br>495 | 94<br>90 |
| | | | | | | | | | 420 | 200 | 95 | 460 | 250 | 96 | 325 | 220 | 94 | 724 | 435 | 82 |
| | | | | | | | | | Too weak to test | | | Too weak to test | | | Too weak to test | | | 500 | 260 | 92 |
| | | | | | | | | | | | | | | | | | | 270 | 180 | 75 |
| | | | | | | | | | 3010 | 365 | 85 | 4190 | 540 | 76 | 4015 | 620 | 71 | 4120 | 420 | 86 |
| | | | | | | | | | 3350 | 390 | 92 | 3970 | 510 | 88 | 4105 | 595 | 82 | *3590 | 395 | 95 |
| | | | | | | | | | 3150 | 360 | 92 | 4250 | 530 | 89 | 4210 | 600 | 83 | 4050 | 415 | 95 |
| | | | | | | | | | 3310 | 390 | 92 | 4310 | 540 | 86 | 4170 | 610 | 81 | 4090 | 420 | 94 |
| | | | | | | | | | | 21.8% | | | 24.8% | | | 28.7% | | | 21.8%<br>17.4% | |

eceived. The test data on the second sample are marked with an asterisk.



/TABLE 5 .....

TABLE 5

Effect of Hot/Dry, Hot/Wet, and Hot/Humid Conditions on Polyether Ur

| Conditions of Test | Period of Exposure, weeks | T.S. | $E_b$ | H | Conditions of Test | Period of Exposure, weeks | T.S. | $E_b$ | H |
|---|---|---|---|---|---|---|---|---|---|
| Material as received | | 4090 | 640 | 93 | Material as received | | 4090 | 640 | 93 |
| Dry, $40^o \pm 0.5^oC$ | 4 | 2960 | 585 | 93 | Immersed in water, $40^o \pm 0.5^oC$ | 4 | 2680 | 550 | 95 |
| | 12 | 2780 | 615 | 93 | | 12 | 1920 | 520 | |
| | 24 | 2350 | 540 | 94 | | 24 | 2850 | 550 | |
| | 52 | 2200 | 615 | 99 | | 52 | 1410 | 510 | |
| Dry, $70^o \pm 0.5^oC$ | 2 | 3580 | 640 | | Immersed in water, $70^o \pm 0.5^oC$ | 2 | 1920 | | |
| | 4 | 3190 | 630 | | | 4 | 1050 | | |
| | 12 | 2740 | 665 | | | 12 | 660 | | |
| | 24 | 2440 | 630 | 95 | | 24 | 600 | | |
| | 52 | 1970 | 660 | | | 52 | 400 | | |
| | 64 | 2045 | 670 | 99 | | | | | |
| Dry, $100^o \pm 0.5^oC$ | 2 | 3480 | 745 | | Immersed in water, $90^o \pm 0.5^oC$ | 2 | 580 | 225 | 85 |
| | 4 | 2540 | 785 | | | 4 | 340 | 90 | 67 |
| | 12 | 1120 | 835 | | | 12 | Too weak to test | | |
| | 24 | 890 | 620 | 94 | | | | | |
| | 52 | 940 | 440 | | | | | | |

A

TABLE 5

ct of Hot/Dry, Hot/Wet, and Hot/Humid Conditions on Polyether Urethane P.U.11

| H | Conditions of Test | Period of Exposure, weeks | T.S. | $E_b$ | H | Conditions of Test | Period of Exposure, weeks | T.S. | $E_b$ | H |
|---|---|---|---|---|---|---|---|---|---|---|
| 93 | Material as received | | 4090 | 640 | 93 | Material as received | | 4090 | 640 | 93 |
| 93 | Immersed in water, 40° ± 0.5°C | 4 | 2680 | 550 | 95 | 40°C, 100% r.h. | 4 | 1990 | 530 | |
| 93 | | 12 | 1920 | 520 | | | 12 | 1960 | 520 | 95 |
| 94 | | 24 | 2850 | 550 | | | 24 | 2860 | 530 | |
| 99 | | 52 | 1410 | 510 | | | 52 | 1730 | 545 | 93 |
| | | | | | | | 96 | 2100 | 545 | 99 |
| | Immersed in water, 70° ± 0.5°C | 2 | 1920 | | | 70°C, 100% r.h. | 2 | 1320 | 715 | |
| | | 4 | 1050 | | | | 4 | 1100 | 725 | |
| | | 12 | 660 | | | | 12 | 690 | 330 | |
| 95 | | 24 | 600 | | | | 24 | 790 | 315 | 92 |
| | | 52 | 480 | | | | 52 | 530 | 155 | |
| 99 | | | | | | | | | | |
| | Immersed in water, 90° ± 0.5°C | 2 | 580 | 225 | 85 | 90°C, 100% r.h. | 2 | 520 | 170 | 89 |
| | | 4 | 340 | 90 | 87 | | 4 | 550 | 150 | 91 |
| | | 12 | Too weak to test | | | | 12 | Too weak to test | | |
| 94 | | | | | | | | | | |

B

S. No. 976/67/DP